Body and Peripheral MRA

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INTRODUCTION

Following the development of breath-hold, contrast-enhanced techniques, MR angiography has become an important tool for the evaluation of patients with abdominal vascular pathology. Specifically, the lack of ionizing radiation, lack of nephrotoxic contrast media and the non-invasive nature of MRA make it a useful modality for abdominal vascular pathology. The objective of this work is to describe the acquisition techniques, relevant anatomy, and pathologic conditions for accurate application of MRA in the abdomen.

MRA TECHNIQUE:

General techniques for MR angiography in the abdomen include localizer images, a fast T2 scan, a dose-timing acquisition, and breath-hold three-dimensional gradient recalled echo images acquired before, during, and following the intravenous administration of gadolinium contrast agent. In addition, delayed, post-contrast T1 weighted gradient echo imaging with fat suppression is helpful. Additional optional scans include two-dimensional cardiac gated phase contrast imagine, as well as three-dimensional phase contrast imaging.

Localizer images are typically obtained using a three-plane localizer acquisition, therefore allowing the visualization of the aorta along its long axis, as well the position of the kidneys posteriorly and the mesenteric circulation anteriorly. Subsequently, a fast, breath-hold T2 weighted image is very useful to evaluate masses incidentally found on the MRA portion of the exam. A fat suppressed single-shot fast spin echo image is highly desirable (HASTE, single-shot fast spin echo). Using these techniques, T2 weighted images can be obtained throughout the abdomen in a single breath-hold, therefore speeding the examination. The heavily T2 weighted single-shot methods are sensitive to fluid, however it should be cautioned that subtle differences in T2 may be masked due to magnetization transfer effects occurring within the fast spin echo sequence. Therefore, these techniques are most useful for confirming cystic fluid collections, rather than complete characterization of all abdominal masses.

Subsequently, the arrival time of contrast agent in the region-of-interest must be determined. Several options for determining the arrival time of contrast media are available, including 1) a dose-timing scan, which a small test dose of contrast agent (1-2 cc) is administered, and serial gradient recalled images are obtained at 1-2 second intervals. The arrival time of contrast can be determined by measuring a region of interest in the serial images [1]. 2) Fluoroscopically-triggered MRA, in which serial gradient recalled images are obtained and rapidly reconstructed so that the individual performing the exam can detect the arrival of contrast agent within the region-of-interest [2]. 3) Automatically triggered techniques, where a sampling volume is placed over the aorta, and the MRI scanner detects the arrival of contrast agent within the sampling volume automatically, triggering the three-dimensional acquisition [3].

For the contrast-enhanced scan, meticulous attention to detail is important to ensure diagnostic studies. Typically, a three-dimensional T1 weighted spoiled-gradient recalled echo acquisition is acquired. Fast gradients are important in order to ensure that a short repetition time (TR) and echo time (TE) are achieved, therefore maximizing spatial resolution per unit time. Images are acquired prior to contrast agent in order to verify that the location of the 3D volume covers the anatomic region-of-interest. In

addition, the pre-contrast image set is used as a mask if mask subtraction is necessary. An image volume is then acquired during the arterial phase of contrast enhancement, followed by an additional volume during the venous phase.

Following the three-dimensional volume acquisition, delayed post-contrast T1 weighted gradient echo imaging with fat suppression is performed. These images are very useful for determining the true size of aortic aneurysms, evaluating venous contrast enhancement patterns for parenchymal lesions that are detected on the 3D contrast MRA, as well for evaluating venous abnormalities including venous thrombosis. These images are typically obtained using an interleaved gradient echo technique in order to optimize signal-to-noise ratio and contrast resolution.

Finally, optional supportive sequences include two-dimensional phase contrast methods for measuring the direction of blood flow, and the volumetric flow rate in selected vessels of interest. Typically, a segmented k-space gradient recalled echo acquisition is used, and is acquired during a single breath-hold. Accurate flow measurements may be obtained if high spatial resolution studies are acquired to limit partial volume errors associated with flow measurement. Three-dimensional phase contrast acquisitions are also helpful, especially in the renal arteries, where the presence of signal void at or distal to a stenosis implies a hemodynamically significant stenosis.

The dose of gadolinium contrast agent required for abdominal vascular imaging is dependent on the resolution that is acquired during the examination. Many studies have been performed demonstrating that a single dose (20 cc) is satisfactory for aortic and renal artery imaging [1]. For high-resolution examinations, it may be necessary to increase the dose to 30 or even 40 cc gadolinium contrast agent. The rationale for the increased dose is that it is necessary to provide consistent arterial enhancement throughout the acquisition technique. Typically, the gadolinium contrast is injected at a rate of 2 cc per second. The contrast administration is followed immediately by a saline flush of at least 20 cc in order to clear the line and flush the contrast agent through the venous system. It should be noted that a saline flush as large as possible should be used, because large saline flushes have been shown to provide greater arterial signal.

AORTA

Aortic Aneurysm: Abdominal aortic aneurysms are defined as localized enlargement of the aorta by 50% of its diameter or more [7]. Most abdominal aortic aneurysms are infrarenal; an estimated 10% are either supra- or juxta- renal. While an infrarenal abdominal aortic aneurysm is considered present when the diameter exceeds 3 cm, the risk of significant morbidity and mortality increases as the size increases, with an estimated 5-year risk of rupture of 25% if the aneurysm exceeds 5 cm in diameter [8].

Magnetic resonance angiography has been shown to be accurate for the detection and delineation of abdominal aortic aneurysms [9]. In addition, MRA is useful for delineation of branch vessel involvement with aneurysm or stenosis. The delayed images on contrast-enhanced exams are also helpful for determining the relationship of the venous anatomy to the aneurysm.

Mycotic aneurysms typically are eccentric and saccular in location, which is atypical for atherosclerotic aneurysms. Common organisms include salmonella and staphylococcus, and inflammatory abdominal aneurysms are seen more commonly in immunosuppressed patients, IV drug abusers, and patients with bacterial endocarditis. Magnetic resonance angiography demonstrates the lumen of the aneurysm in myoctic aneurysms. However, the delayed images on MRA techniques also demonstrate marked enhancement of a thickened rind of aorta in cases of inflammatory aortic aneurysm. The enhancing aortic wall can also be seen in noninfected aortic aneurysms however.

Inflammatory abdominal aortic aneurysms comprise approximately 5% of all abdominal aneurysms Inflammatory abdominal aortic aneurysms comprise approximately 5% of all abdominal aneurysms [10]. Retroperitoneal fibrosis is a special case of inflammatory aortic aneurysmal disease. It is felt to be due to an immune reaction that results in leakage of antigen across the aortic wall, which then triggers a fibrotic immune response to the antigen [10]. This results in extensive retroperitoneal fibrosis associated with the aneurysm. Magnetic resonance angiography, due to its sensitivity to extraluminal soft tissue anatomy, can be useful for following the response of patients to treatment for retroperitoneal fibrosis. The progression and regression of the retroperitoneal fibrotic process can be monitored on serial exams.

Aortic Occlusion: Aortic occlusion typically occurs in the infrarenal abdominal aorta [11]. The majority of aortic occlusions occur due to embolization, often a cardiac source, although thrombosis superimposed on aortic atherosclerotic disease is not an uncommon cause. Other causes of aortic occlusion include thrombosis of an abdominal aortic aneurysm, trauma, dissection, and extrinsic compression of the aorta. In most of these cases, a distal aortic occlusion propagates back to the level of the origin of the renal arteries.

MR angiography techniques are ideally suited for the evaluation of infrarenal abdominal aortic occlusion. Many of these patients have superimposed renal insufficiency, and the relative lack of nephrotoxicity associated with the gadolinium dyes reduces the risk of renal failure in these patients. In addition, the intravenous injection eliminates the need for intraarterial access, which in the case of aortic occlusive disease must occur from an approach in the arm, with a small but significant increase in morbidity associated with catheter-induced complications. It is possible to visualize the common femoral and distal vascular runoff in patients with aortic occlusion using MR angiography due to the complete opacification of blood during the intravenous injection.

RENAL ARTERIES

The clinical consequences of renal artery stenosis include renal vascular hypertension and ischemic nephropathy. Renal artery stenosis is the cause of hypertension in an estimated 1-5% of patients with elevated blood pressure. In addition, bilateral renal artery stenosis, or unilateral renal artery stenosis in a single kidney, is a cause of chronic renal ischemia, and can result in end stage renal disease. An estimated 16% of patients with end stage renal disease have ischemic nephropathy. Causes of renal artery stenosis include atherosclerotic disease in approximately 75%, and fibromuscular dysplasia in approximately 25%. The clinical features of the two diseases are distinct; atherosclerotic disease affects older individuals, and causes proximal renal artery disease. In contrast, fibromuscular dysplasia tends to cause renal artery stenosis involving the more distal renal artery and its branches, and is found in individuals at a younger age.

Renal MRA has been shown to be accurate for depicting proximal renal artery stenoses associated with atherosclerotic vascular disease. High-grade stenoses are often depicted with a small focus of signal loss at the site of the stenosis. For mild to moderate stenoses, it is often helpful to acquire an additional 3D phase contrast exam, which is more sensitive to the signal loss associated with turbulent flow distal to the stenosis.

As discussed above, FMD is known to cause more focal web-like stenosis, often involving the distal main renal artery or its segmental branches. The accuracy of renal MRA in this situation is unknown at this time. It is clear that some cases of FMD can clearly be demonstrated using MRA, however it is necessary to carefully review the MIPs as well as the source images to identify the beaded, irregular appearance of the renal artery. It should be noted, however, that visualization of the segmental renal artery is obscured by enhancement of the renal parenchyma by the gadolinium contrast agent. Therefore, small focal segmental artery stenoses are difficult to identify on renal MRA.

MESENTERIC ARTERIES

Mesenteric ischemia may either be acute or chronic in etiology. Chronic ischemia occurs when there is progressive atherosclerotic occlusive disease of all three mesenteric arteries, and patients typically present with weight loss and chronic abdominal angina. Patients with acute mesenteric ischemia, in contrast, usually present with an acute abdomen and are not suitable candidates for MR due to their altered metabolic and septic status. Chronic mesenteric ischemia is most commonly caused by atherosclerosis with stenotic involvement at the origin of the three mesenteric vessels. Acute mesenteric ischemia is most often caused by embolization, and therefore MRA or CTA may be used to detect the presence of an acute thrombus within the mesenteric artery. Additional causes of acute mesenteric occlusion include aortic dissection with sudden occlusion of the mesenteric vessels due to branch vessel involvement of the flap and vasculitis.

A median arcuate ligament syndrome is an additional, somewhat controversial syndrome, whereby there is compression of the origin of the celiac axis due to the median arcuate ligament, which connects the crura of the diaphragm [14]. The angiographic diagnosis is classically seen as compression of the superior aspect of the artery, and this finding is most often seen in young, thin women. Some patients complain of abdominal pain, weight loss, and nausea, however the relationship of the celiac narrowing to these symptoms is somewhat controversial. The apparent stenosis is often worse on expiration abuse.

The finding is not infrequently seen on magnetic resonance angiography examinations of the abdomen. Repeat imaging during inspiration and expiration may be useful to further characterize whether the lesion is fixed or not. In addition, it is possible to measure blood flow velocity increases at the site of the stenosis, although the role of these flow measurements is currently unclear.

PERIPHERAL ARTERIES

While the 2D time-of-flight techniques have been demonstrated to be accurate in the distal lower extremities, the methods have not been reliable in the pelvic vessels, where artifacts associated with slow and in-plane and retrograde flow are commonplace. The contrast-enhanced three-dimensional gradient recalled echo acquisitions provide superior image quality in the proximal vasculature, since the techniques are flow-velocity insensitive. In addition, the higher spatial resolution achievable with a 3D acquisition, as well as the short echo time, creates better depiction of stenoses.

Several methods have been proposed for imaging the lower extremity vasculature using contrast-enhanced techniques. In general, these techniques include a "bolus chase" technique, where the gadolinium is infused and the table is rapidly moved from the pelvis region to the thighs, and then the distal lower extremities. Three-dimensional gradient recalled echo images are acquired at each station. Typical acquisition parameters include a field of view of 40 cm, TR/TE/FLIP of 4/1.0/30 degrees, matrix size of 320 x 224 x 32, with interpolation to 512 x 512 x 64.

In order for the moving table techniques to work, it is necessary to image fast enough to eliminate the possibility of venous enhancement in the distal lower extremities. Using the moving table techniques, it is generally necessary to image the first two stations in 25 seconds or less, therefore allowing capture of an arterial phase for the distal lower extremities. This can be accomplished by using partial Fourier techniques in the upper stations, which do have some negative effect on the acquired spatial resolution. More recently, parallel acquisition techniques have been used to reduce the time while preserving spatial resolution. In addition, peripheral venous tourniquets have been used effectively to reduce venous enhancement on multi-station MRA.

The other approach for contrast-enhanced evaluation of the distal lower extremity vasculature is to perform three different injections of contrast media at three different locations. For these techniques, the contrast agent dose is divided into three separate volumes, and approximately 0.1 mmol/kg gadolinium is injected for each station. Since timing issues become problematic in the distal lower extremities due to occlusion of proximal vessels, it is highly desirable to use a time-resolved acquisition for this approach, therefore eliminating problems associated with delayed enhancement of the arteries.

Our preferred method uses a hybrid approach, which includes a time-resolved acquisition of the infra-geniculate region followed by a two-station moving-table exam of the proximal vessels. This protocol can be accomplished in less than 30 minutes on state-of-the-art scanners, with minimal oversight by the attending radiologist.

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